Development of 1000 kW Molten Carbonate Fuel Cell (MCFC) Pilot Plant and 250 kW Stack

IHI

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The molten carbonate fuel cell (MCFC) is expected to be ready for commercial use early in the next century. This new type of electric power generation system has a higher thermal efficiency and can reduce CO_2 emissions. IHI has participated in the "New Sunshine Program" of MITI from 1993 and has conducted the development of the MCFC stack and 1 000 kW class power generation system under a contract from NEDO and MCFC Research Association. The development outline of the 1 000 kW class MCFC pilot plant constructed at the Kawagoe test site and the present development stage of the plant control system and the fuel cell subsystem including two 250 kW class stacks developed and manufactured by IHI are described here.

Key words: Fuel cell, MCFC, Molten carbonate fuel cell, Stack, Power generation system, Pilot plant, Control system, Simulation, Stack performance, Operating test

1. Introduction

A fuel cell is a new type of power generating system that can directly convert the chemical energy of fuel into electrical energy. A fuel cell has high thermal efficiency and has low emissions. The molten carbonate fuel cell (MCFC) has one of the highest levels of thermal efficiency, and its efficiency is expected to improve up to about 60 percent in the future. Thus, the MCFC is superior to conventional thermal power plants and to combined-cycle power plants, whose efficiency goal is about 55 percent. Coal gasified gas can be used as fuel, not only natural gas. Thus, the fuel cell can be used in a variety of applications such as small-scale distributed power plants, high-capacity power plants replacing thermal power plants, and coal gasification combined cycle power plants. Also, the MCFC produces less NO_x and has low levels of other emissions. It is also highly efficient and can reduce fuel consumption. The MCFC can be used as a CO_2 separation and utilization system, and can reduce CO_2 emissions. From the standpoint of preventing global warming, the early commercial use of this technology is awaited.

In order to commercialize MCFC power plants, IHI has been working on development of the fuel cell (stack) as well as the power generation system since 1983. In 1984, we received a commission from the New Energy and Industrial Technology Development Organization (NEDO), and started development of 1 kW and 10 kW fuel cells and succeeded in power generation using them. Starting in 1987, we participated in the Moonlight Program of the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry (currently the New Sunshine Program). We were also committed to develop a 100 kW class stack by NEDO, and succeeded in generating a maximum power output of 129 kW (a world record at the time for an MCFC) (1). Meanwhile, the development of power generation plants was commissioned to us by the Technology Research Association for Molten Carbonate Fuel Cell Power Generation System (MCFC Research Association). Starting in 1991, we acquired operating and control technology using the 100 kW class MCFC system and a control test plant (a simulated stack was used for the test) (2). In 1995, we started operating tests on a 40 kW class pilot plant, which was the first domestic plant to run under the electricity enterprises act, and achieved a power plant operation time of 3 800 hours (3).

In 1993, the development of a 1 000 kW class pilot plant was started by the MCFC Research Association. The plant is the first test plant to verify performance and operation characteristics in order to establish a base system for larger scale commercial power plants in the future. However, the plant is not designed to achieve the economy and compactness needed for commercialization. In development work, the manufacturers provide and develop the major equipment and facilities, while electric power and gas companies also participate in the development research. Using the actual results for stack development and plant operations, IHI is in charge of designing the plant. We are responsible for developing the control system, which is the core of the plant, and two 250 kW stacks (half of total fuel cells) as well as the fuel cell subsystem. Therefore, our role is very important in this development project. At this point, the design and construction of the 1 000 kW class pilot plant have been completed, except for the fuel cell stacks which are currently being installed. The plant completed adjustment operation tests using a simulated stack to prepare for the power generation and operation test scheduled for 1999. The test plant is the Kawagoe MCFC Test Station located at the Kawagoe Thermal Power Station of Chubu Electric Power Co., Inc. In this paper, the current status of development of the 1 000 kW MCFC pilot plant will be reported.

2. Development target and development schedule

2.1 Development target

The development targets for the 1 000 kW class pilot plant are shown in **Table 1**. The pilot plant will be used for operations research by combining the results of each developed element (equipment and control system) obtained from the New Sunshine Program. The purpose of this plant is to confirm that the developed elements will operate as a system and to obtain the prospects for commercialization of the plant.

2.2 Development schedule and progress

The development schedule is shown in **Fig. 1**. Basic design started in 1993 and the plant specifications were determined. Design and fabrication of all the equipment except for the fuel cells started in 1994. Installation of equipment began following completion of the building in 1996, and installation was completed in 1997. In 1995, a construction plan was submitted and it was approved without any problems. After installation of the equipment was finished in 1997, the machinery was adjusted individually. Following the adjustment, a PAC (Process And Control) test was performed to adjust operation of the system excluding the stack. The tests include start-up/shut-down of the plant, trip tests, and variable load tests. The stack will be installed next and operations research will start in 1999.

2.3 Operating tests and evaluation

During operations research, which will start in 1999, operating tests will be performed to verify the performance, operating characteristics, and reliability of the stack and the system for the purpose of confirming the development targets. Operating tests will also provide design data and reveal any problems that may prove useful for the proof system. The results of the operating tests will be used to check the level of development target accomplishment in preliminary evaluation (end of 1998) and in final evaluation (end of 1999).

Table 1 Development targets

Item	Target
Rated power	1 000 kW (AC)
Thermal efficiency	45% (gross thermal efficiency) 40% (net thermal efficiency)
Fuel	LNG
Operating time	5 000 hours
Environmental effects	Less than regulated value
Stack decay rate	1 %/1 000 hours

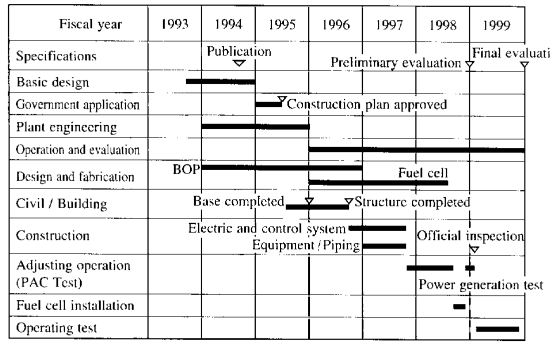

Fig. 1 Development schedule of 1 000 kW class MCFC pilot plant

3. Plant overview

3.1 System configuration

The system configuration of the 1 000 kW class MCFC pilot plant is shown in **Fig. 2**. The basic flow of the processes is as follows. Natural gas (fuel) and steam provided by a heat recovery steam generator are reformed into hydrogen and carbon monoxide by a reformer by a steam reforming reaction. The reformed gas is supplied to the anode of the fuel cell and used for an electricity generating reaction. Oxygen is also needed for the electricity generation reaction of the fuel cell, so air will be supplied by a turbine compressor. At the exhaust gas from the anode, there will be leftover hydrogen and carbon monoxide which have not been used during the reaction. These are supplied to the combustion chamber of the reformer and used as a heat source, which is needed for the steam reforming reaction of natural gas. The combustion exhaust gas from the reformer includes carbon dioxide. This gas will be supplied to the cathode of fuel cell together with air from the turbine compressor and used for the cell reaction. The cathode exhaust gas has a high temperature (670°C max.), so it will be used to run the turbine to recover its power and will also be used as a heat source for the heat recovery steam generator to produce steam for the reforming reaction.

3.2 Examining system efficiency

The system performance of the plant is shown in **Table 2**. For each operating condition, the gross thermal efficiency is 46.7% and the net thermal efficiency is 40.2%. It has been confirmed that these are above the target value of 45% for gross thermal efficiency and 40% for net thermal efficiency.

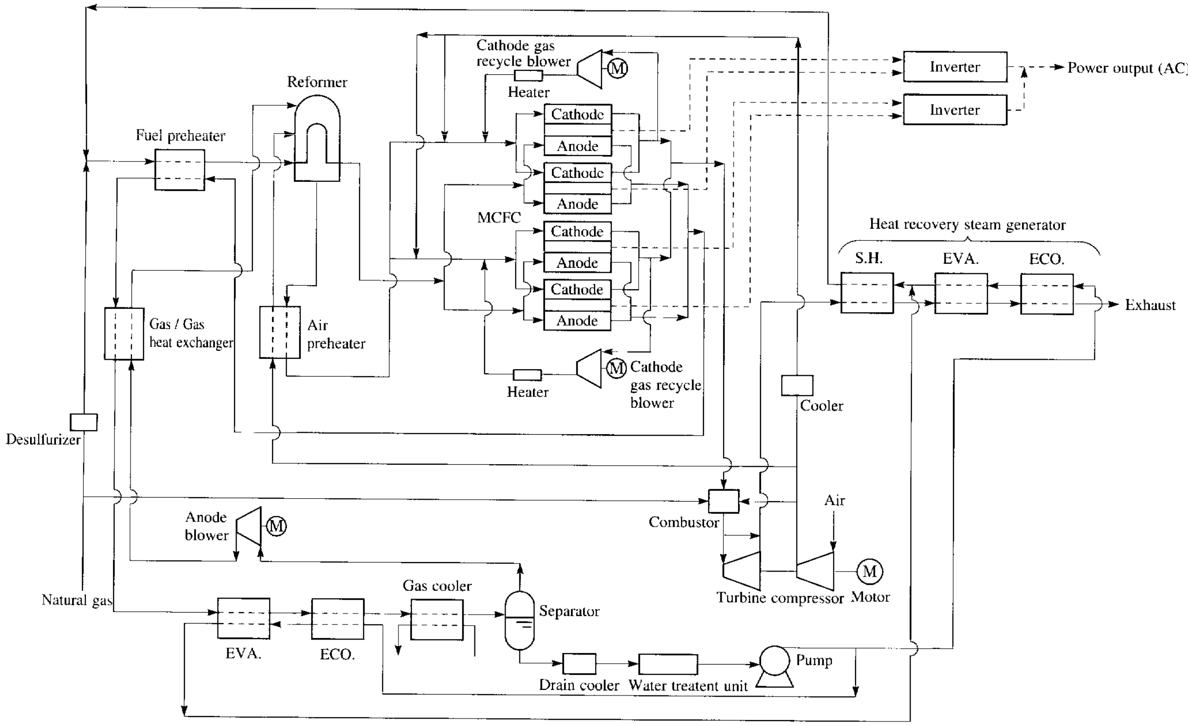

Fig. 2 Flow diagram of 1 000 kW class MCFC pilot plant

Table 2 Calculation results of plant thermal efficiency

Item		Unit	Operation optimizing net thermal efficiency	Operation optimizing gross thermal efficiency
Operating pressure		MPa {kgf/cm²}	0.49 {5.0}	0.49 {5.0}
Stack A	Operating voltage	V	0.786	0.786
	Current density	mA/cm²	100	100
Stack B	Operating voltage	V	0.763	0.763
	Current density	mA/cm²	121	121
Fuel utilization		%	76.2	76.2
Stack A	O_2 utilization	%	26.8	26.8
	CO_2 utilization	%	34.5	34.5
Stack B	O_2 utilization	%	25.1	25.0
	CO_2 utilization	%	34.8	34.8
Steam carbon ratio		—	3.5	3.5
Conversion ratio		%	96.6	96.6
Gross power output		kW	1 000	1 000
Fuel cell power output		kW AC	1 000	1 000
Turbine power output		kW	−19	−109
Auxiliary power		kW	99	189
	Anode blower	kW	23	23
	Cathode gas blower (A, B)	kW	46	46
	Others	kW	11	11
Net power output		kW	901	811
Total fuel consumption		kg/h	147.3	140.9
Fuel consumption of combustor		kg/h	6.4	—
Heating value (HHV)		kJ/kg {kcal/kg}	54 726 {13 071}	54 726 {13 071}
Gross thermal efficiency		%	44.7	46.7
Net thermal efficiency		%	40.2	37.9
Air flow rate		kg/h	3 500	3 500
Cathode gas recycle flow rate	Stack A	kg/h	7 445	7 441
	Stack B	kg/h	7 754	7 755

3.3 Equipment layout

Fig. 3 shows a bird's-eye view of the plant. The major equipment that makes up the plant is four 250 kW class fuel cells (stack), one reformer, two cathode gas recycle blowers, one turbine compressor, and one heat recovery steam generator. Considering the distribution of gas flow, the fuel cell is located symmetrically to reformer of each system. Because the plant is a pilot plant, there is a lot of measuring equipment. Thus the heat loss and the pressure loss tend to increase. However, the machinery layout plan has been devised to keep these losses as low as possible and is also designed for ease of maintenance.

4. Control system

The control system of the 1 000 kW class MCFC pilot plant is based on the MPC (MCFC Power Plant Control System). The configuration is shown in **Fig. 4**. When constructing the control system, the following plans were made to give higher priority to safety and lower cost over stable power supply, since the plant is a testing/research facility.

(1) The equipment can be remote controlled and automatically operated so that about two operators can monitor and operate it.

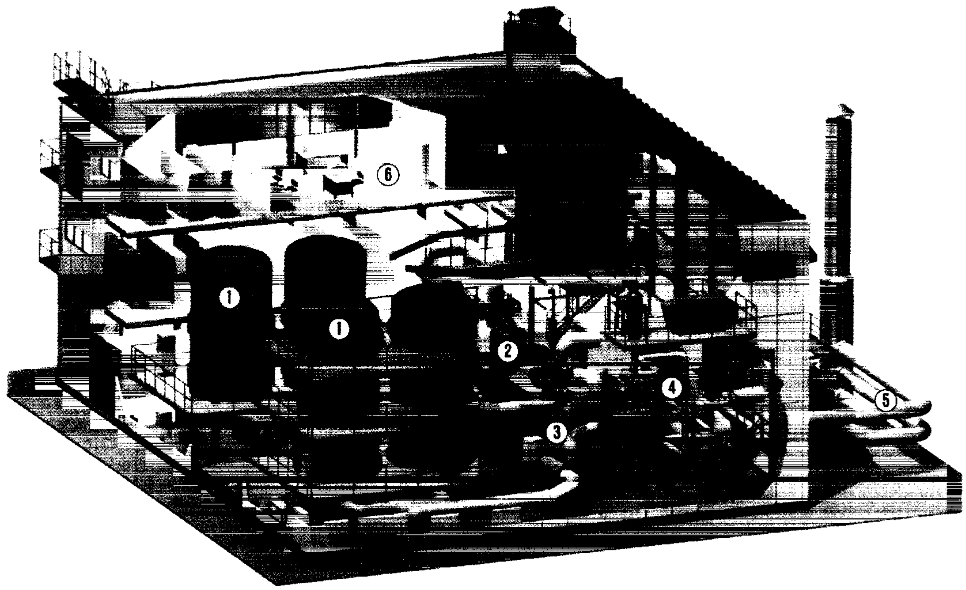

Fig. 3 Bird's-eye view of 1 000 kW class MCFC pilot plant

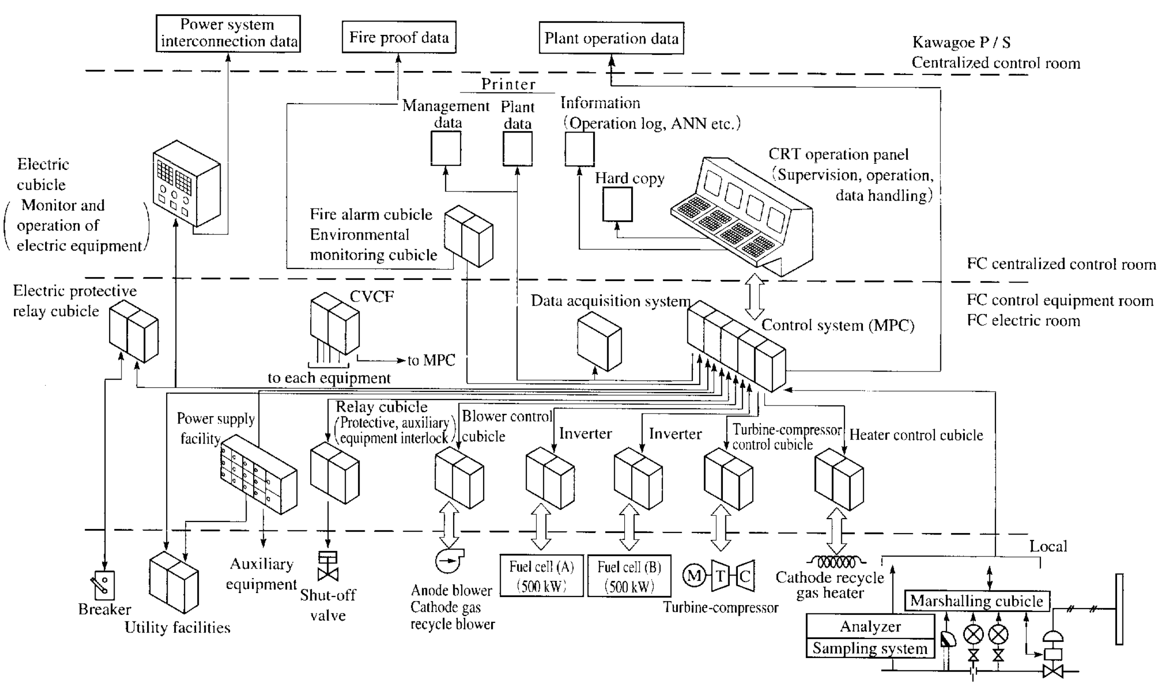

Fig. 4 Control system of 1 000 kW class MCFC pilot plant

(2) The plant can be automatically shut down by interlocks when the plant exhibits abnormal behavior. Manual shutdown by the operators must also be possible.
(3) For the purpose of technical verification and evaluation of the developed elements, a data acquisition system must be installed.
(4) The "2 out of 3 method" is limited only to detectors that are important for safety and control.
(5) Control equipment must avoid hazardous areas

to the utmost. For equipment that needs to be installed inside such areas, appropriate hazard-proof equipment must be selected.

MPC uses a digital control system, which makes it possible to change/adjust the control logic according to the progress of test research. This is a centralized operation and control system that uses CRT operation. One of the important control factors in 1 000 kW class pilot plant is anode/cathode differential pressure control. Fluctuation in differential pressure is predicted to increase, especially when the equipment is tripping. Therefore, the equipment is modeled using heat-mass balance equations and the plant behavior is simulated by computer program beforehand. If any improvement in control logic is necessary, it is checked during the PAC test stage, which is the test without the fuel cells. The anticipated equipment trips are as follows: ① inverter trip, ② fuel cell trip, ③ cathode gas recycle blower trip, ④ reformer trip, ⑤ anode blower trip, and ⑥ turbine compressor trip. The simulation results for these trip conditions are shown in **Table 3** (Case A). **Table 3** shows that there are cases where the anode/cathode differential pressure exceeds the limit value. In order to suppress differential pressure fluctuations during equipment trips, the following method was designed and reflected in the MPC. The method puts both the anode N_2 gas supply control valve (A-valve, see **Fig. 5**) and the cathode gas exhaust control valve (B-valve, see **Fig. 5**) in the stand-by position, and as soon as the shut-valve (which is located downstream of the control valves) is opened, purge gas is supplied/exhausted. In simulation which uses this improved logic, the anode/cathode differential pressure falls within the limit value, as seen in **Table 3** (Case B).

5. Fuel cell system

5.1 System overview and equipment structure

The fuel cell system for the 1 000 kW class pilot plant consists of two 500 kW output subsystems (subsystem A and B). These subsystems can be operated individually. IHI is in charge of fuel subsystem B. A system overview for fuel subsystem B is shown in **Fig. 5**.

Reforming gas from the reformer (the fuel gas), and the reformer combustion exhaust gas and the cathode air from the turbine compressor (oxidizing agent gas) are distributed through the flow control valves to correspond to power output in conjunction with fuel cell subsystem A. The fuel gas and the oxidizing agent gas are equally distributed to the anodes/cathodes of the two 250 kW class stacks, which are installed in a parallel, symmetrical configuration. Part of the cathode exhaust gas is circulated into the inlet of the cathode by the cathode gas recycle blower, which is being developed by Ebara Corporation, and the remaining gas is supplied to the turbine compressor. During start-up, the fuel cell is isolated from the rest of the equipment by the inlet/outlet isolation valve. When the fuel cell temperature is rising, the cathode side temperature is raised using cathode recycled gas heated by a cathode gas heater while the cathode gas recycle blower is in operation, and the anode side temperature is raised using high temperature nitrogen gas heated by a nitrogen gas heater. In order to maintain the performance of the fuel cell during the isolation state, mixed gas with an appropriate gas composition is supplied into the anode and cathode.

5.2 PAC test equipment (simulated stack)

For the PAC test, PAC test equipment (simulated stack) is used to simulate the characteristics of the fuel cell before the actual fuel cell is installed in the system. The fuel cell power output is determined in the following manner. First, a simulation program for fuel cell power output in the control system determines the simulated current that corresponds to output demand. Next, the simulated voltage is

Table 3 Simulation results for 1 000 kW class MCFC pilot plant

Trip items (100% load)	Case A				Case B			
	Cathode-Anode differential pressure (maximum) (mmAq)		Vessel-Cathode differential pressure (maximum) (mmAq)		Cathode-Anode differential pressure (maximum) (mmAq)		Vessel-Cathode differential pressure (maximum) (mmAq)	
Trip (ANN)	±800 (400)		±800 (400)		±800 (400)		±800 (400)	
Set point	59		30		59		30	
Inverter trip	1 125	△	581	○	469	○	259	◎
Inverter (A) trip	564	○	362	◎	564	○	362	◎
Inverter (B) trip	786	○	369	◎	487	○	319	◎
Fuel cell trip	1 675	△	−778	○	741	○	444	○
Fuel cell (A) trip	493	○	291	◎	493	○	291	◎
Fuel cell (B) trip	1 290	△	−676	○	498	○	375	◎
Cathode gas recycle blower trip	1 752	△	−855	△	774	○	540	○
Cathode gas recycle blower (A) trip	500	○	296	◎	500	○	296	◎
Cathode gas recycle blower (B) trip	1 354	△	−740	○	510	○	455	○
Reformer trip	1 691	△	−770	○	754	○	440	○
Anode blower trip	1 041	△	−691	○	592	○	431	○
Turbine compressor trip	1 571	△	−648	○	603	○	369	◎

(Note) 1. Numerical value in this table is simulation results for fuel cell (B).
2. ◎ : Differential pressure is within ±400 mmAq
○ : Differential Pressure is ±400 mmAq to ±800 mmAq
△ : Differential pressure is over ±800 mmAq
3. Modified logic for the reduction of the differential pressure is not executed at the trips of Inverter (A), Fuel cell (A), and Cathode gas recycle blower (A), because the maximum differential pressures in those trips are kept within ±800 mmAq.

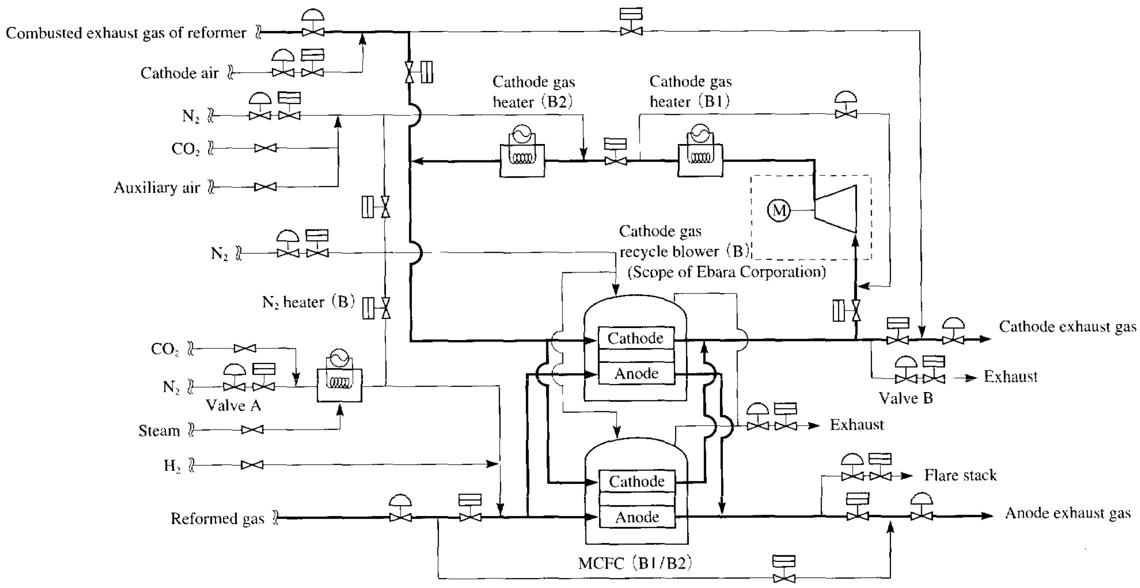

Fig. 5 Process flow diagram of fuel cell subsystem B

calculated according to the operational conditions of the fuel cell. To simulate the heat caused by the fuel cell reaction, an anode heater and a cathode heater for PAC test are installed at the corresponding simulated anode/cathode and provide simulated heat. To simulate an increase in gas at the anode, superheated steam is injected into the simulated anode terminal. Similarly, a decrease in cathode gas is simulated by exhausting cathode exhaust gas out of the system. To simulate the pressurized vessel of the fuel cell stack, which is the basis for anode/cathode differential pressure control, a pressurized vessel is installed for the PAC test.

6. Development of 250 kW class stack

6.1 Stack specifications and manufacturing schedule

IHI's 250 kW class stack in fuel cell subsystem B consists of two 125 kW class sub-stacks that are installed in the top and bottom of the pressurized vessel. A total of four sub-stacks are to be manufactured. (These sub-stacks will be referred to as No. 1 sub-stack through No. 4 sub-stack, in the order of production.) **Fig. 6** shows a bird's-eye view of the 250 kW class stack. The anode and cathode gases enter the vessel separately at the bottom, and are distributed to the upper and lower sub-stacks inside the vessel. After reaction, they are exhausted from the bottom of the vessel. The two sub-stacks inside the pressurized vessel are connected in parallel for gas supply, but are connected in series electronically. Inside the sub-stack, seventy layers of 1 m^2 class (electrode area) cells with a cell surface area of "Tatami" (Japanese mat) size are placed above and below the intermediate gas holder. Also, inside of the sub-stack, springs are placed at the top and bottom to apply a fixed pressure

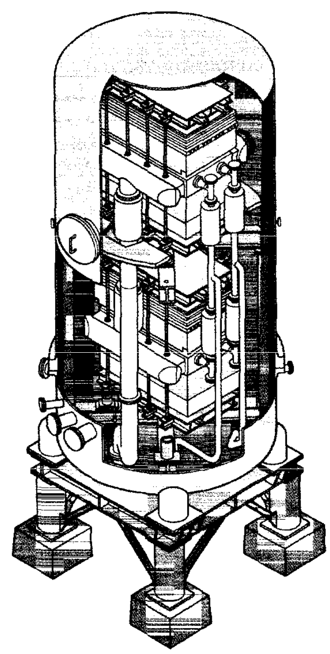

Fig. 6 Bird's-eye view of 250 kW class stack

through rods to tighten the cells. An external view of the No. 1 sub-stack in a pre-assembly stage is shown in **Fig. 7**. One characteristic of our stack is the adoption of an internal manifolded and co-flow type of configuration. The specifications for the 250 kW class stack are listed below.

Rated output	250 kW class
Stack configuration	125 kW sub-stack × 2
Stack structure	Intermediate gas holder type

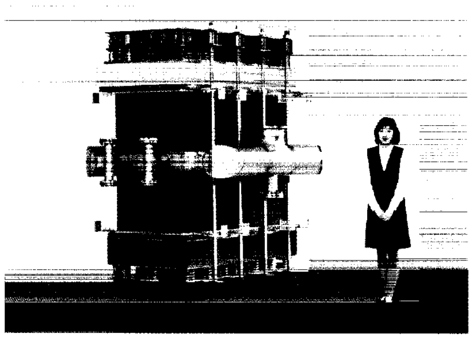

Fig. 7 125 kW sub-stack

Manifold type	Internal manifolded type
Gas supply method	Co-flow type
Cooling system	Cathode gas cooling
Total number of cells	280 cells
Electrode area	1.015 m^2

Fig. 8 shows the manufacturing schedule for the 125 kW sub-stacks. Manufacturing started in 1996. The No. 1 sub-stack was assembled in July, 1997, and later checked for various performance factors in the power generation testing facility inside the factory. After the test, it was put into a special storage container filled with dry nitrogen gas. It was kept in the factory until it was shipped to Kawagoe MCFC Test Station in January, 1999. The No. 2 sub-stack was assembled in December, 1997. Like the No. 1 sub-stack, it was put into a special storage container after the performance check. The production of two sub-stacks was completed in 1997 without any problems. The No. 3 sub-stack was assembled in April, 1998. After the power generation test, it was removed from the testing facility in July, and kept inside the factory. The No. 4 sub-stack was assembled in August, 1998. After the power generation test, it was removed from the testing facility in November. As with the other sub-stacks, they were put into special storage containers and delivered to the Kawagoe MCFC Test Station.

6.2 Contents of the factory tests

Each sub-stack is assembled in a humidity controlled factory, and later installed in the power generation testing facility inside the factory for various performance tests as well as to check its soundness as a stack. The test equipment inside the factory is operated under atmospheric pressure, so the test cannot be performed at 0.49 MPa, which is the operating pressure of the 1 000 kW class pilot plant. Also, the maximum capacity of the power generation facility at the factory is of the 50 kW class, and therefore cannot operate at the rated output of the sub-stack (125 kW). Instead, the power generation test is performed under a partial load condition. As a result, the factory test cannot be carried out under the same conditions as those of the 1 000 kW class pilot plant. The performance of the stack under the actual plant operating conditions is predicted from the analysis and results of the partial load characteristics found during the factory test.

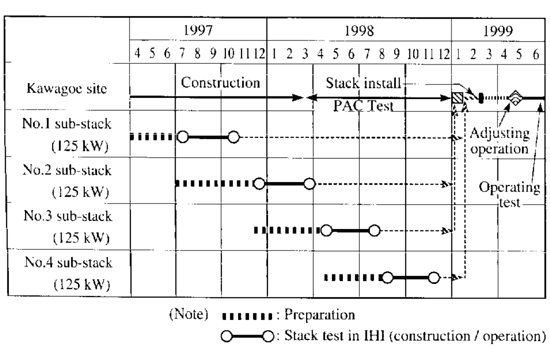

Fig. 8 125 kW sub-stack fabrication schedule in IHI

6.3 Results of the factory power generation tests

Table 4 shows the check items for the factory test and the test items that have been performed for the No. 1 – No. 4 sub-stacks. During the factory tests, the sub-stacks were installed in the test facility, checked for insulation, and the temperature is raised. After the temperature reached the rated value, gas leakage was measured to confirm soundness, and fuel gas was supplied. Distribution of open circuit voltage (OCV) was checked at this point and no problems were found. For example, the OCV distribution of the No. 3 sub-stack showed that the average cell voltage for the 140 cells was 1 038 mV and that the standard deviation (which indicates variations among cells) was 2 mV. It was confirmed that no short circuits, no gas leakage or other problems were found. It was also confirmed that the OCV values of the No. 3 and No. 4 sub-stacks were the same as those of the No. 1 and No. 2 sub-stacks, which had already completed testing. After confirming that there were no problems in OCV, power generation was started under low load conditions to find the stack characteristic (I-V characteristic). The factory test was performed using nearly the same gas conditions and gas utilization of the 1 000 kW class pilot plant operating conditions. The power generation test was carried out in the range of 20 mA/cm^2 – 50 mA/cm^2. **Fig. 9** shows the cell voltage distribution of the No. 1 – No. 3 sub-stacks at a maximum current density of 50 mA/cm^2.

Table 4 Contents of 125 kW sub-stack test

No.	Contents of test	Current density (mA/cm^2)	Test result			
			No. 1	No. 2	No. 3	No. 4
1	Stack insulation level at room temperature	–	Good	Good	Good	Good
2	Gas leakage by calculating mass balance	0	Good	Good	Good	Good
3	Measurement of OCV and its standard deviation	0	Good	Good	Good	Good
4	Measurement of I-V characteristics and prediction of stack voltage on plant condition	from 20 to 50	Good	Good	Good	Good
5	Measurement of stack insulation resistance	–	Good	Good	Good	Good

There are subtle differences due to differences in fuel utilization and cathode gas composition, but the average cell voltage is 810 – 817 mV and the standard deviation is 5 – 6 mV. The results for the No. 4 sub-stack tests were nearly the same as those for the No. 1 – No. 2 sub-stacks. This confirms that all four stacks have similar properties as already seen in the OCV characteristics.

6.4 Results of dielectric strength test

The dielectric strength test is one of the pre-operation test items that will be performed after the sub-stacks are delivered and installed at the Kawagoe MCFC Test Station. The dielectric strength test at the actual plant will be performed after two sub-stacks are installed inside the sealed pressurized vessel. Therefore, to simulate the test at the actual plant, the sub-stacks were cooled off after the factory test and a dielectric strength test was carried out while the stacks were in the pressurized vessel. The electric resistance of the insulators before and after the electrical resistance test was more than 100 MΩ. Thus the soundness of the electrical resistance was confirmed. The result of the dielectric strength test, on the other hand, showed no time dependent changes in charging current after voltage was applied. The results confirmed good dielectric strength performance.

6.5 Predicted fuel cell performance under the 1 000 kW class pilot plant test conditions

Because there are differences between the 1 000 kW class pilot plant test conditions and the factory test conditions, the fuel cell performance under the actual plant operating conditions has been predicted using the results of the factory tests, etc. The results of the 20 kW class stack test, which was the test preceding the 250 kW class, were used for performance predictions. A cell performance analysis model (referred to as the "cell model" hereafter), which was verified during the test, was also used for performance prediction. First, a comparison was made between the I-V characteristic data (20 – 50 mA/cm^2) of the sub-stack and the analysis results using the cell model. The results are shown in **Fig. 10**. **Fig. 10** shows a good match between the analysis results and the sub-stack test results. On the other hand, the 20 kW class stack test result showed a good match between the cell model analysis result and the test result from low current density to the current density of the 1 000 kW class pilot plant operating conditions (121 mA/cm^2). Therefore, it was judged that the performance of the 125 kW stack at a current density of 121 mA/cm^2 (normal pressure) could be predicted using the cell model. The actual prediction method is as follows. First, the sub-stack performance at the rated current density is given using the cell model. Next, the additional pressure is compensated for to find the sub-stack performance under the actual plant operating conditions. The cell voltage was 781 mV as a result of prediction. Because the planned cell performance value for the 1 000 kW class pilot plant under the same conditions is 763 mV, the performances of the No. 1 – No. 4 sub-stacks are considered to satisfy the planned values.

7. Installation and adjustment tests

7.1 Installation

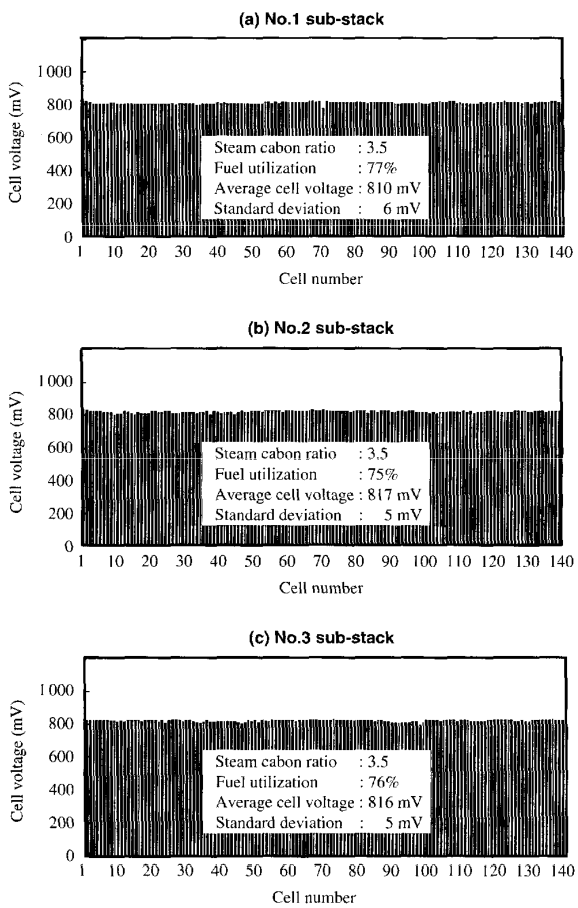

Fig. 9 Cell voltage distribution of No. 1 – No. 3 sub-stack (Current density: 50 mA/cm^2)

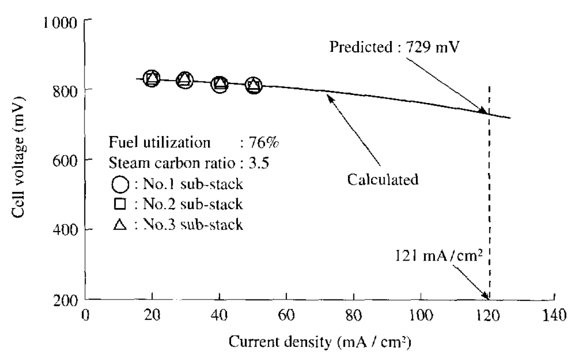

Fig. 10 125 kW sub-stack (No. 1 – No. 3) I-V characteristic

Installation of the machinery started in April, 1997. Piping construction, flushing, and pressure tests were completed without any problems. By the end of January, 1998, hot insulation and painting were finished. For the fuel cell system equipment, it was necessary to decrease heat loss in high-temperature areas as much as possible. Thus a high performance thermal insulating material with a low thermal conductivity was used for hot insulation. The installation method was also carefully considered. For example, to decrease the heat loss from piping supports, the thermal insulator was sandwiched between the supporting equipment. For installation of the electrical and control system, loop checks were done after cable laying, and the sequential masters of the control system and the plant interlocks were checked. Finally, adjustment of the various equipment was completed by the end of January, 1998.

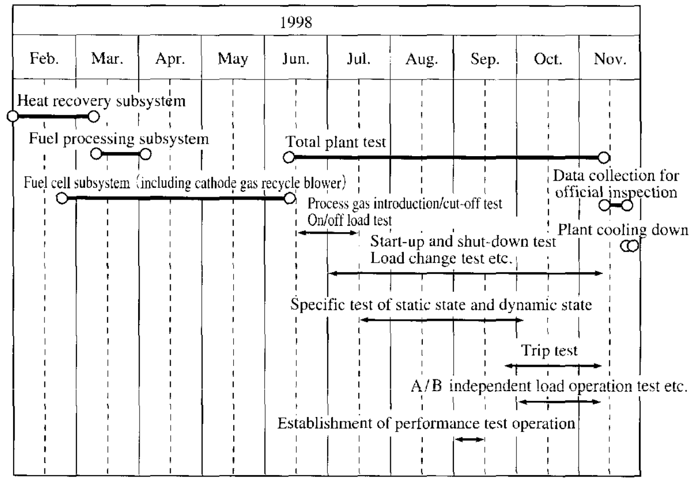

Fig. 11 PAC test schedule of 1 000 kW class MCFC pilot plant

7.2 PAC test and overall adjustment

The PAC test schedule is shown in **Fig. 11**. Adjustment of the system and equipment was carried out in the order of the plant start-up process starting in February, 1998. The adjustment tests for the fuel cell in an isolated state have been completed. The overall plant operation tests have already finished, including the following: process gas introduction/cut-off test using the simulated stack, on/off load test, load change test, specific test of static state, start-up/shut-down test, and trip test.

When the fuel cell stack is installed in February, 1999, the power generation tests of the integrated plant, with both fuel cell stack and inverter, will begin. Process gas will be introduced into the fuel cell after the temperature and pressure of the stacks are increased. After the inverter is put in parallel, load operation will start and will be adjusted towards the planned 100% load condition.

8. Conclusion

As part of developing the 1 000 kW class pilot plant, IHI has mainly been assigned the design of the plant and the design, manufacture, and installation of several system components. We have designed the control system, which is the core structure of the plant. IHI also designed, manufactured, and installed 500 kW worth of the fuel cell system, which is half the output of the plant. For the control system, we pre-investigated the differential pressure control of the fuel cells using computer simulation, and reflected the results in design. The PAC test was performed after the installation of the plant equipment excluding the fuel cells. The 250 kW sub-stacks were manufactured and pre-tested at the works to confirm that they satisfied the planned performance requirements. After installation of the stack, we will join in the operations research, which will start in 1999. We plan to create base data using the test results so that the plant and stacks can be evaluated in terms of the development targets. Using the results obtained by development of the 1 000 kW class pilot plant, IHI will continue to make efforts for early commercialization of MCFC power generation plants.

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